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First record of invasive green algae *Caulerpa racemosa* var. *cylindracea* in Oran Bay (Western Algeria)

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Caulerpa racemosa var. *cylindracea* (hereafter *Caulerpa cylindracea*) was first reported in the Mediterranean Sea in 1926 [1] in Tunisian waters and then in Tripoli harbor in Libya, in 1990. In late 90s it invaded the southern shore of Europe. In Algeria, this invasive species was reported for the first time in 2007[2], five years after it appeared about 450 km from the first site in the eastern part of the Oranian littoral. This situation required widespread monitoring of this invasive species all along 124 km of the coastline. More than 10 stations were patrolled and monitored since then, studied by scuba diving between the surface and 30 m depth.

The observations devoted to the distribution of *Caulerpa cylindracea* in Oran showed that specimens presented the same appearance with irregularly entangled branched stolons attached to the substrate by colorless rhizoids from which the name of the variety cylindracea was derived. Chronologically, the invasion direction seems to move from the bottom to the surface with an orientation from east to west, in the Oranian coastline. *In situ* observations confirmed high propagation speed of Caulerpe in the Oranian coastline where invasions were signaled in several stations. The seaweed was observed for the first time in late 2011 and early 2012 (*pers.obs*) in Arzew Gulf (Cap Carbon) at the extreme east of the littoral, where the first fronds were noticed. Then it extended geographically to the center of the coastline, in Kristel, early 2013. In 2014, it was observed in Ain Turc and Cap Falcon. In 2015, it was observed in the western shoreline near Bousfer beach and in 2016 it reached the "Plane" island (Paloma).

This alien species was encountered at depths ranging from a few centimeters in microcuvettes up to 37 m, on various substrates (hard, sandy, muddy) between marine phanerogams rhizomes and, also between the lower mid-littoral and infra-littorals superior algae, with *Posidonia oceanica* herbarium. The study suggested a strong need for scientific monitoring and management program, using optimized methodslike biological control or manual eradication for controlling the invasion.

[Keywords: Invasive algae, *Caulerpa cylindracea*, Oran coastline, Algeria]

Introduction

Caulerpa racemosa var. *Cylindracea* hereafter referred to as *C. Cylindracea* is an exotic species (sometimes also referred to as an alien, introduced, non-indigenous or non-native species), gets introduced intentionally or unintentionally after having established a population and spreading wild in the new host region[3]. This species, native of south-western Australia, was escribed for the first time in Tunisian waters[1] and then in Lybian waters[4]. But the invasion danger represented by *Caulerpa racemosa* was pointed in early 90s[5,6,7].

In its original habitat, this species lives in balance with its natural environment and its population is controlled by several ecosystem interactions, such as predation, parasitism, and diseases. However, this species can immediately settle in a new environment and become invasive, causing biological disturbance in the marine coastal ecosystems [8, 9,10].

In Algeria, since 2007, *Caulerpa cylindracea* has been mainly located in the central region of the Algerian coast, where it covers a wide variety of substrates ranging from mud to rocky bottoms[2]. It was reported at different depths during phytosociological follow-up of macrophyte populations in different coastal zones of Algiers area and became widely spread in Algiers Bay in a very short time[2,11,12].

C. cylindracea was first identified in Bou-Ismail in 2006[2], Bordj El Kiffan in the East of Algiers[11], and in different areas of Algiers coast[12]. On the Algerian west coast, this algae was reported in Mostaganem[13,14] by the presence of several stands in the Gulf of Arzew, Stidia, and near the port of Salamandre at the West of Mostaganem.

Oran shoreline faced this situation of invasion from East and North Algeria, also accentuated by Almeria-Oran current which sweeps the Algerian coast accelerating the invasion process coming from Spain (South European shore) where it was reported in several cities, including Almeria (Andalusia) 30 m of isobath[15], and the anthropogenic factor stay the most incriminated[36,39].

This study clearly indicated the invasion of the Oranian coast by *Caulerpa cylindracea*, since 2012. The 124 km long coast was a subject of spatio-temporal prospection and bathymetric follow-up of coastal ecosystem, already weakened by anthropization and littoralization. The objective was to provide a map of the chronological invasion and spatial distribution of the species and to describe its bathymetric distribution and its interaction with the local ecosystems including the associated flora and fauna.

Materials and Methods

Few protocols are designed specifically for signaling exotic species and invasive alien species to help facilitate early understanding of the relative risk of invasion of marine coastal ecosystems by different species[16]. This in turn helps to identify potential invasion patterns and target management efforts to reduce additional risks. These data can also be used to facilitate identification of the area's most likely to be invaded in the future.

The present study depicted the recent situation of *Caulerpa cylindracea* on the Oranian coastline, North-West coastal fringe of Algeria, using scuba diving as a means of study at the depth ranging between 25 and 30 m, based on the field data obtained, focusing on the morphological, bathymetric, recovery status and associated fauna and flora[17].

Study area

The Oranian coastline is located on the southern shore of the Mediterranean basin about 432 km from the capital Algiers. The coastal line extends over 124 km and represents 1/10 of the national coastline. Along this zone, more than 10 stations were identified and explored (Fig.1) by way of autonomous diving at 30 m depth (photic zone) during different periods (winter and summer). Each station was transected from the shore to the large[18,19].

The stations were selected to represent all types of habitats, depths, substrates, and wave exposure conditions, from the surface to the deepest area reached in each transect. In the second stage (during the ascent), each benthic community was carefully examined for characterization of the fauna and associated flora.

Study methodology

The survey was based on the observations made by recreational divers already aware of the situation and their personal statements. Surveillance and sensitization campaigns among sea users, fishing vessels, yachtsmen and divers helped to detect the presence of the exotic species, following the supply of information cards distributed previously to facilitate its recognition.

Once the stations were chosen, the methods used varied according to the nature of the habitat of each station and also on the available financial and logistical resources. The monitoring was carried out at each exit by two divers (Fig. 2), which followed a linear transect perpendicular to the littoral and carried out in summer and in winter to detect the presence of the species in relation to the two seasons[20]. Only individuals or colonies with at least 50% of the area within the strip transect were considered and counted to avoid distorting the sample[21].

During this process, care was taken to control propagation of the species in other areas by the use of non-destructive methods. The organization of such protocol of early warning system ensured rapid transmission of information so that an assessment and

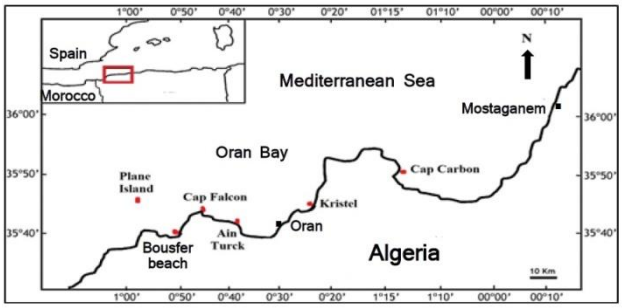

Fig. 1 — Presentation of the Oranian littoral and the stations invaded by *C. cylindrcea*.

Fig. 2 — Prospection and diving surveys on random transect to study *C. cylindrcea* in Oran coastline.

corrective action can be proposed (cf. Marine Alien Invasive Species Strategy for the MedPAN Network, 2012). The identification sheets were used for marine exotic species in the Mediterranean[17] and the international standardization procedure for the mapping evaluation of *Caulerpa taxifolia*[22,23]

Results and Discussion

Although the transport of algae on floating woods has been considered for some distant colonies, most of them have an anthropogenic origin[24,38]. In Oran, this was the first work concerning the introduction and invasion of marine algae on a regional scale. The presence of the Caulerpe was reported in the Eastern region of Oran[25,26] at "Port aux Poules" harbor and at Cap Carbon between 2 and 7 m depth.

It was found that the seaweed frequented the Oranian coast since 2011-2012 (*pers.obs*), precisely, at Cap Carbon in Arzew zone[9,26]. The eastern littoral welcomed the first fronds of *C. racemosa* var. cylindracea, which installed first as spots of disseminated individuals in the biocenosis of photophilic algae of the upper infra-littoral. Several *C. racemosa* individuals were detected at Cap Carbon in 2012, at 0.3 m depth in a small bedrock cuvette (Fig. 3). This first signaling allowed for follow up of its distribution, knowing that the species was absent or never encountered in the rest of the Oranian littoral.

Species identification

Caulerpa cylindracea is a green marine chlorobionte (green alga) recognized by its creeping axes (stolons) with rhizoids and upright fronds with ramules in the form of vesicles, sized between 1 and 11 cm and characterized by a sexual and vegetative reproduction. Observations on the distribution of *C. cylindracea* in Oran since 2012 showed that the specimens present the same appearance with irregular and entangled branched stolons attached to the substrate by colourless rhizoids (Fig. 4).

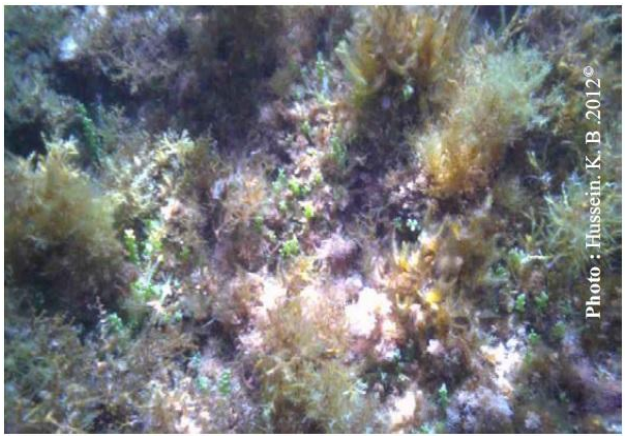

Fig. 3 — First signaling of *C. cylindracea* in Cap Carbon at 30 cm depth, Gulf of Arzew, Estern Oranian coasts, 2012.

Spatio-temporal evolution of invasion by C. cylindracea

Caulerpa cylindracea invasion occurred from east to west along the Oranian coastline, chronologically since 2011-2012, the species spread to the extreme west in only four years (Fig. 5).

The affected stations with their GPS position are represented in Table 1.

The sense of invasion was the same as the one which affected the Algerian coast. After the first signaling in Algeria in 2006 at Algiers harbor, this species was present in the west coasts after only five years, which highlighted the speed of its distribution and the need to control this invasion Reaping in view the detected consequences on the communities and coastal ecosystems of the Algerian coastline. Its presence on the western Algerian coasts was monitored to better assess the extent of its proliferation, given that the invasive variety of *Caulerpa racemosa* spread in Algeria in a very short time[25].

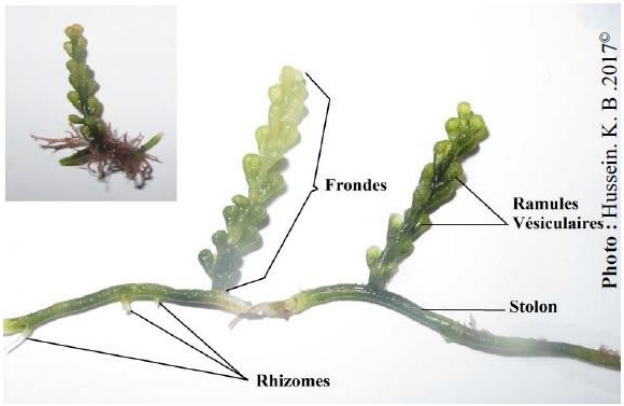

Fig. 4 — Specimen of *Caulerpa cylindracea* present in Oran Bay.

Fig. 5 — Geographical, chronological invasion and habitat characterization of *C. cylindracea* in the Oranian coastline.

Table 1 — Geographical coordinates for invasions by *C. cylindracea* in the Oranian coastline.

Location	Latitude	Longitude	bottom	Depth	Year*
Cap Carbon	N 35° 54' 11.6706"	0° 20' 23.4414"	Rocky, seagrass	0.3-8m	2012
Kristel	N 35° 50' 29.2992"	0° 29' 3.6132"	Sandy/Galets	1.5m	2013
Ain Türck	N 35° 44' 13.4802"	0° 43' 43.338"	Sandy/Galets	3m	2014
Cap Falcon	N 35° 46' 16.4742"	0° 47' 33.6876"	Rocky	5m	2014
Bousfer beach	N 35° 43' 33.8484"	0° 50' 55.9386"	Rocky/Sandy	1m	2015
Plane Island	N 35° 46' 16.0278"	0° 54' 10.3206"	Rocky	0.2-37m	2016

*Year of the First Observation

All *in situ* surveys and *in visio* monitoring showed that the invasion spots were mainly represented by low density communities with modest tangle rates and the presence of small tufts, indicating a recent invasion, and hence the felt need to take early and urgent measures to control its geographical distribution and to limit its impact on the marine environment.

Bathymetry

Found at depths ranging from few centimeters to 37 m, the invasive species also occupies various substrates (hard, sandy, muddy) between the rhizomes of marine phanerogams and also between the lower mid-littoral algae and the upper infra-littoral algae associated to *Posidonia aceanica* herbarium and on dead matter.

Scientific survey dives indicated that invasion by *C. cylindracea* in the Oranian coastline took place from the bottom to the surface. In fact, in all the study sites, sea grapes were always observed first at a depth of more than 2 m, and later at the surface, spread in small crevasses between the mid-littoral and the upper infra-littoral. Algerian waters were invaded around Algiers in 2006, Mostaganem littoral in 2008 and then Oranian coastline in 2011-2012; the introduction vector remains unknown at present. This rapidity could be explained by its reproduction mode, in synergy with anthropogenic activities. Figure 6 shows an update of its distribution in the Mediterranean basin as well as new indications of the species in the west Algerian water duly integrated.

Situation of C. cylindracea in Oran

Cap Carbon Station

In 2010, the species was reported in the Gulf of Arzew[13,14] and in 2012 it was observed at Cap Carbon[9] as isolated fronds in an area of 2 m^2 of a rocky micropiscine (Fig. 7) between tufts of *Cystosiera.* sp, *Coralina elongata* and *Ulva* at a depth of 0.2 m. The species was encountered in 2013 between 1 and 3 m depth with *Posidonia oceanica* herbarium[9].

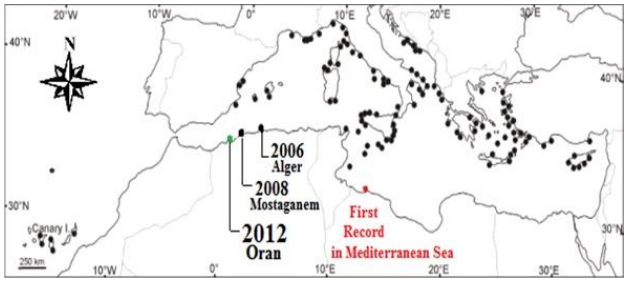

Fig. 6 — Updated map of *C. cylindracea* distribution in the Mediterranean and North Atlantic (Canary Islands). Red dot: First signaling in Libya[8] modified; green dot: First signaling in the Oranian coastline, 2017.

Fig. 7 — *C. cylindracea* at Cap Carbon in 2012 east of the Oranian littoral.

Cap Falcon Station

Cap Falcon was the most infected site with 90% of recovery to a depth of 5 m. In some rocks, the spots were characterized by ramulas with bulky vesicles (Fig. 8), indicating an old invasion with large fronds. This could be attributed to the maritime traffic at this station, favored by the presence of a local boat house.

"Plane" island (Paloma) Station

C. cylindracea invaded the island in 2014, where a spot of 30 fronds was found at 37 m, in June 2016, during the beginning of the summer season. It surfaced and settled in a micro-cuvette with a covering rate of 70% at a depth of 0.3 m on a surface of 1 m^2 characterized by fronds of 5 cm (Fig. 9).

Fig. 8 ─ *C. cylindracea* at Cap Falcon in 2014 in the center of the Oranian littoral.

Fig. 9 ─ Spot of *C. cylindracea* at "Plane" Island in 2016 West of the Oranian littoral.

During the winter season, around mid-December, a marked decrease in the occupied area was observed due to the reduction in foliar production of the species marking the dormancy state of its life cycle. This was the best time to treat the phenomenon of the biological invasion of *C. cylindracea* on the Oranian coast by manual eradication of the spots to stop its spread and to maintain the equilibrium of infected spaces[17,40,41,42]. Several individuals were recorded recently in 2017 on the wall of a steep rocky cliff underwater near the landing stage of the island at 8 m of isobath.

Flora and associated fauna

So far algae sharing the same biotope as *C. cylindracea* is concerned, there was dominance of rhodophytes (*Lithophyllum* sp, *Peyssonnelia* spp and *Mesophyllum* sp), sciaphil algae chlorophytes (*Codium bursa*, *Flavellia petiolata*, and *Halimeda tuna*), and phaeophytes, (*Cystoseira* sp).

In the enclaves (<1 m deep), photophilic algal biocenosis competed in space with *C. cylindracea*, In the case of Ulves, *Enteromorpha*, *Carolina elongata* and *Dichtyota dictyotoma* were abundant. Other non-indigenous algae that colonized the Mediterranean also competed in space, as in the case of *Asparagopsis armata* and *A. taxiformis*; the indigenous species are represented by microalgae which recover the rocky walls. It also frequented the upper limits of the *Posidonia oceanica* herbarium as found in Cap Carbon.

For associated fauna, the dominant species were: Sessile filtering organisms, such as Greek bathing sponge *Spongia officinalis* sponges, *Chondrosia reniformis*, *Crambe crambe*, sessile and vagile micro invertebrates. These used *C. cylindracea* spots as shelter which attract considerable ichthyofauna[35]; fronds can be disseminated and settled on any surface, with species such as the anemones *Anemonia viridis*, sea tomato *Actina equina* and polychaete *spirograph* sp. Also encountered were the populations of echinoderms common urchin *Paracentrotus lividus*, sea star *Hacelia attenuata*, and sea cucumber *Holothuria* sp and fish juvenile: bogue *Boops boops*, golden mullet *Liza aurata*, *Gobidea*, Mediterranean rainbow wrasse *Coris julis*, *Trypteregion delesai* and comber *Serranus* sp, which continually frequented the stollons.

Intreaction of C. cylindracea with native benthic communities

The colonization of the substrate by *C. cylindracea* seemed to affect the evolution of the benthic communities in terms of diversity, abundance, and seasonal dynamics[8,27,28,35], probably due to the presence of *C. cylindracea* that modifies the physico-chemical parameters in the sediments[29].

This seaweed is eaten by several herbivorous fish, mainly sparidae: the bogue *Boops boops*, the axillary seabream *Pagellus acarne*[30], the saupe (*Sarpa salpa*) and *Spondyliosoma cantharus*[37]. It is also consumed by the common sea urchin (*Paracentrotus lividus*) and the granular sea urchin (*Sphaerichinus granularis*), as well as molluscs (*Aplysia* sp, *Ascobulla fragilis*, *Bittium latreilli*, *Elysia tomentosa*, *Lobiger serradifalci* and *Oxynoe olivacea*).

The invasion effects of *C. cylindracea* on the functioning of ecosystems may depend on the feeding choice of herbivores between native and non-native algae. Competition of *C. cylindracea* with macroalgae on space may increase habitat disturbance. In a study in southern Sicily[31] investigating the feeding preferences of *Paracentrotus lividus* exposed to native macroalgae and non-native species, it was found that over a period of 48 h, *P. lividus*

preferentially consumed *C. cylindracea* and *D. membranacea* (mixture of non-indigenous macroalgae), when the mixture of native macroalgae had barely been consumed.

In addition, our observation suggested that potential control and bioremediation by *P. lividus* on propagation might be possible when the invasive species coexisted with other indigenous macroalgae. The presence of toxins in this variety and their potential effects on herbivorous fauna and on the movement of organic matter through trophoblastic chains remained to be established, including the last consumer who is man.

Conclusion

The work presented allowed preparation of an initial inventory of the invasion by *C. cylindracea* at the level of the coastal zone of Oran. It is particularly an invasive species given that only five years from the first signaling in Algeria were sufficient for this species to invade the Oranian coast, to colonize and disturb the ecosystem, resulting in a reduction of the indigenous phytobenthos[32, 33, 34].

In recent years, the Oranian coastline is experienced a galloping trend of anthropogenic activities on the maritime façade with the presence of one of the most important ports of Algeria, which remain exposed to an intense fishing activity and maritime traffic.

The detailed map and recent data from the original *in situ* surveys supplemented by underwater photographs confirmed high propagation speed of *C. cylindracea* in the Oranian littoral, which allowed signaling of the invasion in several stations. Indeed, the seaweed frequented the eastern coasts of Oran beginning in 2011-2012, precisely, the zone of Arzew - Cap Carbon[26,9], that welcomed the first fronds of *Caulerpa cylindracea*. Then it extended its geographical repartition area to the center in 2013 precisely in Kristel. In 2014, it reached Ain Türck and Cap Falcon and in 2015 it settled in the western coast of Oran at Bousfer beach, and finaly in 2016, it was found in the “Plane” island (Paloma).

The investigations carried out on the Oranian coast have so far been partial; the observations reported in this study provided the dimension of the tasks still to be accomplished. It would be desirable to extend similar research to other stations on the Oranian seaboard on the one hand and on the other hand to rocky and littoral bottoms, to better control and evaluate its dangerous spread in this important and vulnerable zone.

The study also provided interesting reflection on the state of *C. cylindracea* to take measures to signal other invasive species and to propose management of invaded habitats. The scientist will have the heavy task of finding the method(s) to control this invasion, for example, the use of biological control or manual eradication techniques. It is certain that the marine ecosystem has been affected in recent decades by the impact of a growing population and what it generates as exhaustion of natural resources, most often by using non-controlled pressures. Climate change and industrialization are also amplifying the degradation of these ecosystems. Faced with this problem, it appears that the only way to hope preserving ecosystems is to establish follow-ups at different levels of the affected coastline.

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